Surface modification of titanium with lasers

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1 INTRODUCTION

In practical use the surface of a material will be subjected to the influences of the environment. Therefore, the surface of the material is usually considered as being the most important part of any engineering component. In the field of materials engineering the affecting mechanisms involve both wear and corrosion. Although a particular selection for a specific material can be made on the basis of both the required surface and bulk properties, it is obviously more efficient to combine a relatively cheap substrate material with the appropriate surface layer. Therefore, a panoply of surface engineering techniques have been applied to modify the surface layer in order to enhance the mechanical performance.

Actually, the appropriate technique depends on the required layer thickness. At modest loads, under sliding contact conditions, protection can be provided by means of CVD and PVD processes, since the layer thickness amounts to several micrometers. At high contact loads, a thicker hardened layer is required, which can be provided by means of plasma spraying and laser processing. In contrast, the latter techniques are capable of modifying the surface layer over several hundreds of micrometers. This thesis will concentrate on laser surface modification of light weight materials, in particular titanium, in order to enhance its wear and corrosion resistance under conditions of high contact load.

More than 200 years ago, titanium was found to be present in a mineral, later called rutile. The new metal was named after the Titans, i.e. the powerful sons of Uranus and Gaea out of the (Greek) mythology (also τιτανοσ: plaster of Paris). The element Ti is the fourth most abundant metal in the earth's crust. The high strength to weight ratio and its excellent corrosion resistance makes titanium extremely suitable as material for many applications in the field of aerospace and chemical engineering. In addition, Ti exhibits a high melting temperature and can be used at temperatures up to 550 °C with good fatigue, creep and toughness properties. The request for specific demands is satisfied by the versatile range of Ti alloys. However, a more widespread use has frequently been inhibited as a result of its poor tribological properties. Therefore substantial effort has been put into the surface engineering area of research in order to obtain protective coatings and thereby to widen the potential range of applications beyond that of construction material.

An advantage of laser processing is the capability to heat up or to melt the surface layer very locally, as in practice wear is often restricted to specific areas. Another advantage is the possibility to manipulate the laser beam by means of an optical system to modify the surface of complex geometrical objects. In addition, laser processing is contactless and the thermal-mechanical deformation of the substrate is generally low.

To explain the microstructural properties of the modified layer, it is necessary to know the variation in temperature during laser processing. The maximum temperature attained is related to the occurrence of phase transitions and chemical reactions. Furthermore, high temperature gradients are involved during cooling down, which determine the size and type of the microstructural features. As the thermal expansion of the applied coating constituents and the substrate material differ, high thermal stresses arise during cooling down, which finally may result in crack formation. In chapter 3 an analytical model is presented to predict the temperature profile depending on various process conditions. The model includes different intensity distribution of the laser beam, different types of cooling and the finite dimensions of the specimen.

In chapter 4 and 5 two different routes are presented to obtain a protective coating on Ti. The microstructure is examined in great detail by scanning and transmission electron microscopy. Firstly, laser surface hardening of Ti in the liquid state is carried out by the process of laser gas alloying (chapter 4). At high temperatures, new phases are formed by the reaction of the substrate material with the gaseous environment. Furthermore, the crack behaviour of the TiN layers has been studied. Finally, the mechanical performance of the modified layers is examined.

Secondly, metal-matrix-composites are produced by the laser particle injection processing route (chapter 5). The particles are entrapped during solidification of liquid Ti. As the injected particles partially dissolve, depending on the process conditions, new phases are formed in the matrix, which significantly influence the mechanical performance. In particular, the interfacial region between Ti and SiC particles is closely investigated. Therefore, hardness indents are performed to examine the crack initiation and the propagation behaviour at the interface. Finally, sliding wear tests are performed under boundary lubrication conditions.